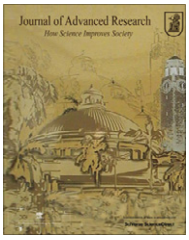
Journal of Advanced Research (2012) 3, 279–286

Cairo University

Journal of Advanced Research



ORIGINAL ARTICLE

Effect of surface roughness and adhesive system on repair potential of silorane-based resin composite

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Received 4 July 2011; revised 18 September 2011; accepted 23 September 2011
Available online 6 November 2011

KEYWORDS

Bond strength;
Methacrylate-based resin composite;
Repair;
Silorane-based resin composite;
Surface roughness

Abstract This study was performed to evaluate the influence of surface roughness and adhesive system on the repair strength of silorane-based resin composite. Twenty-four substrate discs from silorane-based Filtek P90 were made and stored for 24 h. Half of the discs were roughened against 320 grit SiC paper while the other half was polished against 4000 grit SiC paper. All discs were etched with phosphoric acid. Repair resin composite, Filtek P90 or Filtek Z250, was bonded to the treated surfaces using their corresponding adhesive; P90 System Adhesive (SA) or Adper Scotchbond Multipurpose (SBMP) ending up with four repair groups. The groups were as follows: G1: Smooth + SA + Filtek P90; G2: Roughened + SA + Filtek P90; G3: Smooth + SBMP + Filtek Z250; G4: Roughened + SBMP + Filtek Z250. Additional six unrepaired discs from each resin composite (G5 and G6) were prepared to test the cohesive strength. After 24 h, discs (n = 6/group) were serially sectioned to obtain sticks (n = 30/group) for microtensile bond strength (μTBS) testing. Scanning electron microscopic (SEM) evaluation of substrates that received different treatments as well as representative substrate-repair sticks from each group were performed. Modes of failure were also determined. Two-way ANOVA with Repeated-Measures revealed that surface treatment and repair material had no significant effect on repair bond strength of silorane-based composite material. Paired t-test showed that all repair strength values were significantly lower than the cohesive strength of Filtek P90. Adhesive failure was the predominant mode of failure which was confirmed by SEM. Surface treated Filtek P90 composite showed different textures under SEM whereas phosphoric acid did not produce clear changes. An interaction layer between

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Peer review under responsibility of Cairo University.
doi:10.1016/j.jare.2011.09.003

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SBMP adhesive and Filtek Z250 repairing composite was detected. Repair of the silorane composite was successful irrespective of the surface roughness and chemistry of the repair material used. However, it did not reach the cohesive strength of the material.

Introduction

Polymerization shrinkage is one of the clinicians' main problems when placing direct resin-based composite restorations [1]. Therefore, several attempts were done to reduce the shrinkage by changing the nature of the resin. Currently, a new cationic ring opening silorane-based monomer system, with the target profile of a low shrinking and biocompatible composite that withstands the aggressive oral environment, became available in the market [2,3]. However, fractures and failures, such as discoloration, worn areas and poor anatomic form of these restorations can still occur [4].

Successful resin repair requires development of an adequate interfacial bond between the old and new resins. Composite repair studies have addressed several ways to improve the composite–composite bond including mechanical and/or chemical surface treatments [5–7]. Surface treatments include roughening with diamond burs [5], silicon papers, carborundom stones [8], finishing discs [9] sandblasting [8,10], air abrasion with AlO_3 or silica [11] as well as chemical conditioning using hydrofluoric acid or phosphoric acid [6]. Silane coupling agent may or may not be added [9,12]. The use of an intermediate adhesive agent was also found to play an important role in the repair bond [12,13]. While surface roughness promotes mechanical interlocking, the adhesive agent may enhance surface wetting and chemical bonding with the new composite [12]. Self-etching adhesive systems were developed to simplify adhesion procedures [14]. Self-etching systems can be used to condition both the surrounding tooth and the composite to be repaired in one procedure which is more practical [7]. The effectiveness of those systems in repairing composites that were six years old was confirmed [7].

Repair of light-cured dimethacrylate resin composites has been extensively investigated and reported [5–7,12,15–20]. Clinically, immediate repair by primary bonding between resin composite layers could be achieved due to the presence of an oxygen inhibited layer (OIL) of unpolymerized resin as well as due to direct cross-linking with unreacted active radicals [21,22]. On the other side, delayed repairing is fraught with difficulties including the exposure of the restoration to an oral environment that enhances the decaying of unreactive methacrylate groups with time [23]. Finishing and polishing of composites accelerate the reduction of reactive groups and expose the inorganic filler particles to the surface that may not present further bonding ability [22]. It has been stated that the greatest monomer functional groups' radical activity can be found on the composite surface during the first 24 h after polymerization [24]. Meanwhile, there are some clinical situations that may require the repair of a restoration after 24 h from its placement. This emphasizes the fact that repair strength is strongly dependant on the time frame between restorative procedure and repair. Also, in many clinical situations, when the clinician decides to repair a composite restoration, he or she may not have complete information about the nature of the restorations to be repaired including whether they are dimethacrylate-based or silorane-based resin composite. As silorane-based resin composite represents a new version of the resin composite, there is no enough information to reach consensus about its proper repairing method. Immediate bonding to silorane was first addressed by Tezvergil-Mutluay et al. [25] and Shawkat et al. [26]. Shawkat et al. [26] confirmed the possibility of immediate bonding to silorane resin composite.

Therefore, the aim of this study was to evaluate the influence of surface roughness and adhesive systems on the repair bond strength of 24 h aged silorane-based composite. The null hypothesis tested was that the difference in surface roughness and repair material would not influence the 24 h composite-repair microtensile bond strength of silorane-based resin composite.

Material and methods

Specimens preparation and grouping

The resin composite restorative materials and adhesive systems used in the present study are listed in Table 1. Twenty-four cylinder-shaped substrate composite discs (5 mm diameter and 4 mm height) were made. This was done by insertion of Filtek P90 (3M ESPE, St. Paul, MN, USA) in a split Teflon mold (5 mm in diameter and 4 mm height) placed on top of a Mylar strip and a glass slab. Caution was taken during the insertion in order to avoid entrapment of air voids. The top of the increment was also covered with a Mylar strip and compressed with a glass slide in order to obtain a flat surface of the specimen after light curing. The top and bottom surfaces of the resin composite were cured from both sides for 40 s each using LED light curing unit (Blue phase C5, Ivoclar Vivadent, Schaan, Liechtenstein) with an output light intensity of $\geqslant 500\ mW/cm^2$ that was periodically checked using a LED radiometer (Kerr Corp., Orange, CA, USA).

After curing, the disc was removed from the mold and cured from two vertical sides that were previously in contact with the internal surfaces of the mold for an extra 20 s each. The composite discs (substrate) were stored in water at 37 °C for 24 h. Half of the discs were wet-roughened against 320 grit SiC paper for 15 s corresponding to the roughness obtained by diamond bur grinding [27] (roughened group). The mean surface roughness value (Ra) was determined as 0.42 ± 0.06 μm with the Surface Roughness Tester (Model TR1, Time Group Inc., Shangdi, China). The other half were wet-polished using 2500 then 4000 grit SiC paper for the same period (smooth group). All discs received acid etching with 37% phosphoric acid (3M ESPE) for 15 s followed by rinsing with water for another 15 s and then were air-dried for 15 s from a distance of 1 cm. Discs of each group (roughened or smooth groups) were further equally divided ($n = 6$), to receive either P90 System Adhesive (SA) or Adper Scotchbond Multipurpose (SBMP). Adhesive systems were applied as presented in Table 1. Each

Table 1 Materials used in the present study.

Material (manufacturer)	Composition (Lot number)	Application steps
P90 System Adhesive (3M ESPE, Seefeld, Germany)	**Primer**: phosphoric acid-methacryloxy-hexylesters mixture, 1,6-hexanediol dimethacrylate, copolymer of acrylic and itaconic acid, phosphine oxide, (dimethylamino) ethyl methacrylate, Bis-GMA and HEMA, water and ethanol, camphorquinone, silane treated silica filler with a primary particle size of about 7 nm **Filler loading** = 8–12 wt% (8AY)	Primer was applied with a microbrush on the substrate surface and rubbed for 15 s, gently air dried and cured for 10 s
	Bond: Substituted dimethacrylate, TEGDMA, Phosphoric acid methacryloxyhexylesters, 1,6-hexanediol dimethacrylate, camphorquinone, silane-treated silica fillers. **Filler loading** = 5–10 wt% (8AY)	The bottle of the bond was agitated first, then the bond was applied with a microbrush, exposed to a gentle air stream for 10 s and cured for 10 s
Adper Scotch Bond Multipurpose (3M ESPE, St. Paul, MN, USA)	**Conditioner**: 35% H3PO4, silica thickened (7KL) **Primer**: HEMA, polyalkenoic acid copolymer, water, ethanol (7BL) **Adhesive**: Bis-GMA, HEMA (7PY)	Primer was applied on the substrate surface with a microbrush and left for 30 s; then gently air dried for 5 s Adhesive resin that was applied with a microbrush and cured for 10 s
Filtek P90 (3M ESPE, St. Paul, MN, USA) shades (A3 and B2)	**Resin**: ECHCPMS, bis-3,4-epoxycyclohexylethyl-phenyl-methylsilane, camphorquinone. Fillers: Silanized quartz/ yttrium fluoride 0.1–2.0 μm **Filler loading** = 76 wt% (53 vol%) (9ET and 9BH)	Applied in two increments
Filtek Z250 Shade (B2) (3MESPE, St. Paul, MN, USA)	**Resin**: Bis-GMA,UDMA, Bis-EMA **Fillers**: Zirconia/silica 0.01–3.5 μm **Filler loading** = 84 wt% (60 vol%) (9AL)	Applied in two increments

Bis-GMA: bisphenol A glycol dimethacrylate; HEMA: 2-hydroxyethyl methacrylate;TEGDMA: triethylene glycol dimethacrylate; ECHCPMS: 3,4-epoxycyclohexylcyclopolymethylsiloxane; UDMA: urethane dimethacrylate; Bis-EMA: bisphenol A ethoxylated dimethacrylate.

disc was then reinserted while the treated surface was directed upwards in another specially constructed repair mold (5.1 mm in diameter and 7.5 mm in height). Such height was obtained by assembling three split Teflon molds over each other; the first one has a height of 3.5 mm, the second one with a height of 2 mm and the last one with a height of 2 mm. Resin composite discs that received P90 System Adhesive were repaired using Filtek P90 resin composite (shade B2) and those treated with SBMP were repaired using Filtek Z250 resin composite (shade B2). A different shade was chosen for the repairing composite in order to enable visual identification and orientation of the repair interface during μTBS testing and failure mode observation. The repairing composite was packed against the treated side of the Filtek P90 substrate discs incrementally (1.5 mm thick followed by 2 mm thick). Each increment was cured for 40 s ending up with 7.5 mm in height. Six additional discs of 5 mm diameter and 7.5 mm height were prepared from each resin composite (Filtek P90 and Filtek Z250) to test their cohesive strength. All specimens were stored in water at 37 °C for 24 h before sectioning.

Microtensile bond strength testing

Specimens were fixed to the cutting machine (Isomet, low speed saw, Lake Bluff, Ill) and serially sectioned to obtain multiple beam-shaped sticks. From each disc within each group, five sticks were tested, resulting in 30 specimens. The cross-sectional area ($0.9 \pm 0.01\ mm^2$) was confirmed with a digital caliper (Mitutoyo digital caliper, Mitutoyo Corp., Kawasaki, Japan). For microtensile testing, each stick was fixed to the testing jig attached to the universal testing machine (Lloyd LRX; Lloyd Instruments Ltd., Fareham Hants, UK) using cyanoacrylate adhesive (Rocket, Dental Venture of America, Inc., Corona, CA, USA). The sticks were stressed in tension at a crosshead speed of 0.5 mm/min. The load at failure was recorded in N and the bond strength was calculated as MPa by dividing the load by the cross sectional area at the bonded interface.

Data were analyzed using the SPSS program for windows (Statistical package for Social Sciences, release 15 for MS Windows, 2006, SPSS Inc., Chicago, IL, USA). Two-way ANOVA with Repeated-Measures was used to test for surface roughness and adhesive system effects and their interaction. Paired t-test was used to compare between the cohesive strength values of Filtek P90 and Filtek Z250. Student's t test was, also, used to compare between the mean values of the repair groups and the cohesive strength values of Filtek P90. $p < 0.05$ was considered statistically significant.

Scanning electron microscope examination of treated surfaces, repair interfaces and failed sticks

Two additional Filtek P90 substrate composite specimens from each different treatment (smooth, smooth with acid etching, roughened, roughened with acid etching) were prepared to be examined. Also, five representative substrate-to-repair sticks from each group were processed for scanning electron microscope (SEM) observation, in order to examine the surface texture and to characterize the repair interfaces in longitudinal

section. Each substrate-repair stick was wet polished using SiC paper of increasing grit size (1000, 1200, 2500, 4000), rinsed with water for 30 s, and then left to air-dry in a desiccator. The two parts of each failed stick were removed from the fixture with a scalpel blade to be examined to determine the mode of failure as cohesive in resin composite, adhesive at the interface (substrate side or repairing material side) or mixed (adhesive at the interface and cohesive in the resin composite). Treated composite substrates, repaired sticks, and failed parts were then mounted on an aluminum stubs, sputter coated with gold, and observed using SEM (SEM 515; Philips, Eindhoven, Netherlands) at magnifications of 80×, 150×, and 500×.

Results

The results of the present study are summarized in Table 2. Two-way ANOVA with Repeated-Measures indicated that there were no statistically significant effects for surface roughness ($p = 0.88$) and repair material ($p = 0.59$). Also, there was no significant interaction ($p = 0.57$) between the variables (surface roughness and repair material). The cohesive strength of the Filtek P90 and Filtek Z250 resin composites were 52.1 ± 20.2 MPa and 60.0 ± 22.5 MPa, respectively which were not statistically significant ($p > 0.05$). Paired *t*-test revealed a significantly lower repair strengths' mean value for G1 ($p = 0.002$), G2 ($p = 0.007$), G3 ($p = 0.007$), and G4 ($p = 0.009$) when compared with the cohesive strength of Filtek P90 resin composite. Fig. 1 shows the distribution of failure modes among the experimental groups. The predominant failure mode was adhesive. Mixed mode of failure was recognized only for the roughened groups.

SEM evaluation of surface-treated Filtek P90 composite substrates revealed different textures, whereas roughening with 320 grit SiC paper (roughened group) produced superficial scratches (Fig. 2 and 3). Chemical treatment with 37% phosphoric acid did not produce clear changes in the superficial texture of the composite similar to the untreated one (Fig. 2). SEM evaluation of substrate-to-repair slabs showed different interfacial features (Fig. 3). It was observed that there was an interactive layer (about 13–20 μm) between SBMP adhesive and Filtek Z250 repairing composite material (Fig. 3d). Such an interactive layer was not present between P90 System Adhesive and Filtek P90 resin composite (Fig. 3a and b). SEM confirmed the predominance of adhesive failure in all tested groups especially at the substrate side (Figs. 4 and 5) while some mixed modes were detected for roughened groups (Fig. 5).

Discussion

The aim of the present study was to evaluate the repair bond strength of 24 h aged silorane resin composite using, as much as possible, a practical protocol. The protocol encountered either surface roughness of silorane resin composite or not, followed by the use of phosphoric acid etching after which an intermediate adhesive system of either P90 System Adhesive or Adper Scotchbond Multipurpose was applied. This protocol was chosen for several reasons; one of them is that many practitioners do not have additional tools in their dental practice such as chair-side air abrasion or silica coating devices. The usage of diamond finishing burs and acid-etching with phosphoric acid as surface treatment in repair procedure are the most common repair approach taught by European [28] and North American dental schools [29]. Another reason is that often the repair process includes both enamel and dentin together with old composite, thus, etching with phosphoric acid followed by application of an adhesive system is clinically mandatory. In the present study, two different adhesive systems with their corresponding resin composites were used as it is not always possible for the dentist to determine the composite brand required to be repaired.

Based on the results of the present study, the null hypothesis has to be accepted since there was an insignificant difference between the delayed repair bond strength of the tested groups. SEM observations revealed that chemical treatment with 37% phosphoric acid for smooth and roughened surfaces did not produce obvious changes in the superficial texture of the substrate composite compared to that of untreated surfaces. Consequently, acid etching seems to exert only a cleaning effect, without contributing to composite/composite micromechanical adhesion, as mentioned in previous studies [5,12,15].

The present study revealed an insignificant difference between the bond strength of roughened and smooth groups. This finding is supported with Cavalcanti et al., findings [10]. On the contrary, others have reported significant differences between roughened and smooth groups [12,15,20]. Previous researches have explained such inconsistent results in different ways. Some authors referred this variability to the difference in coarseness of the diamond burs used among the studies and consequently the obtained surface roughness [6,15]. However, others attributed such diversity to the resulting surface debris. Surface debris might interfere with proper penetration of primers and/or monomers into the underlying layer [30]. However, those who found such differences between roughened and smooth specimens have used the shear test

Table 2 μTBS values (MPa) of the repairing groups of FiltekP90.

	Repairing method	μTBS Mean and standard deviation (SD)	% of repair strength in relation to FiltekP90 cohesive strength
G1	Smooth/acid etch/SA/Filtek P90	29.9 (9.7)[a]	58
G2	Roughened/acid etch/SA/Filtek P90	32.8 (8.7)[a]	63
G3	Smooth/acid etch/SBMP/Filtek Z250	32.7 (13.4)[a]	63
G4	Roughened/acid etch/SBMP/Filtek Z250	33.4 (10.3)[a]	64
G5	Control Filtek P90 resin composite	52.1 (20.2)[b]	100
G6	Control Filtek Z250 resin composite	60.0 (22.5)[b]	–

Same letter means no significant difference (paired t-test, $p > 0.05$). $n = 30$/each group. SA: P90 System Adhesive; SBMP: Adper Scotchbond Multipurpose.

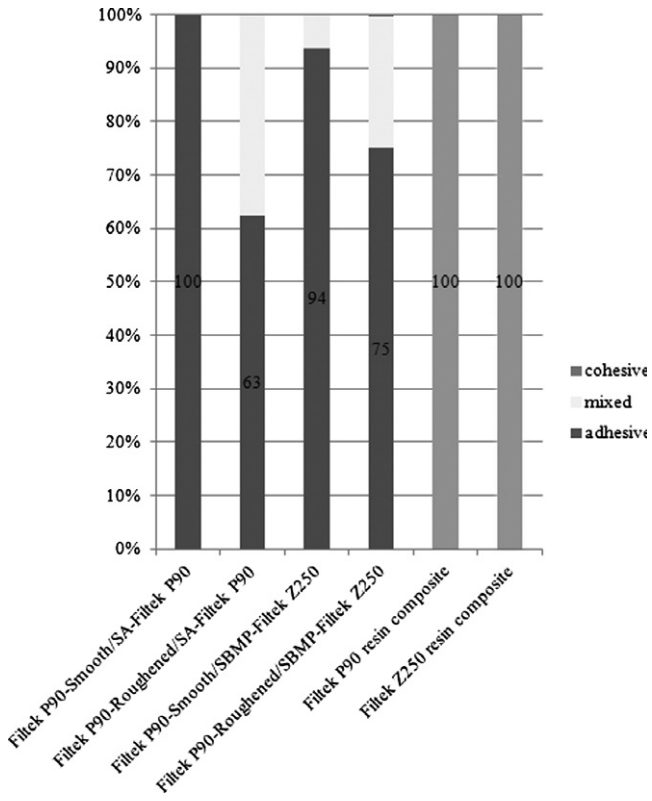

Fig. 1 Percentage distribution of failure modes in all tested groups.

[12,15,20] which differs from the μTBS testing method applied in the present study. Consequently, such dissimilarity in the findings could be explained based on the difference in testing methods, particularly the direction of load application, among the studies. The present study SEM micrographs supports this explanation by showing that the resin filled depressions were in the same direction that coincide with the direction of pulling tensile forces. Meanwhile, in shear testing such depressions were perpendicular to the applied forces increasing the chance to reveal high bond values and more cohesive failure modes for roughened groups. This suggestion may also explain why Luhrs et al. [31] found that sand blasting which creates multi-directional depressions revealed better μTBS than wet-polishing with 600-grit abrasive paper. Many researchers [12,15,20] have used shear bond strength (SBS) for testing the repair bond strength; however, such method has been criticized for the test arrangement that produces high stress concentration at the point of contact [32].

The findings of the present study may highlight the importance of the intermediate adhesive system (IAS) application. During composite repair, there are three possible mechanisms for bonding; chemical bond to the matrix, chemical bond to the exposed filler particles as well as micromechanical retention caused by penetration of the monomer components to the micro-irregularities in the matrix [8]. For the fillers, in case of no surface treatment, the quartz in Filtek P90 is surface treated with an oxirane functionalized silane. Therefore, there is expected chemical affinity between the treated fillers and the P90 System Adhesive. However, in the present study, mechanical (with finishing or polishing) and chemical (after acid etching) treatments were applied to the surface of Filtek P90, which in turn, removed the functional silane from the exposed fillers rendering them with no affinity to both adhesives tested. Based on this, the micromechanical and/or the chemical coupling to the resin matrix is expected to be the cause of the obtained repair bond strength of Filtek P90 and its adhesive. According to Tezvergil-Mutluay et al. [25], immediate chemical bonding is expected to occur between the phosphate group with oxirane and the acrylate group with dimethacrylate. The present study's new finding may point out that some reactive unreacted monomers may still present after 24 h in Filtek P90. For the SBMP, there is no chemical affinity between its components and Filtek P90; thus, micromechanical retention may

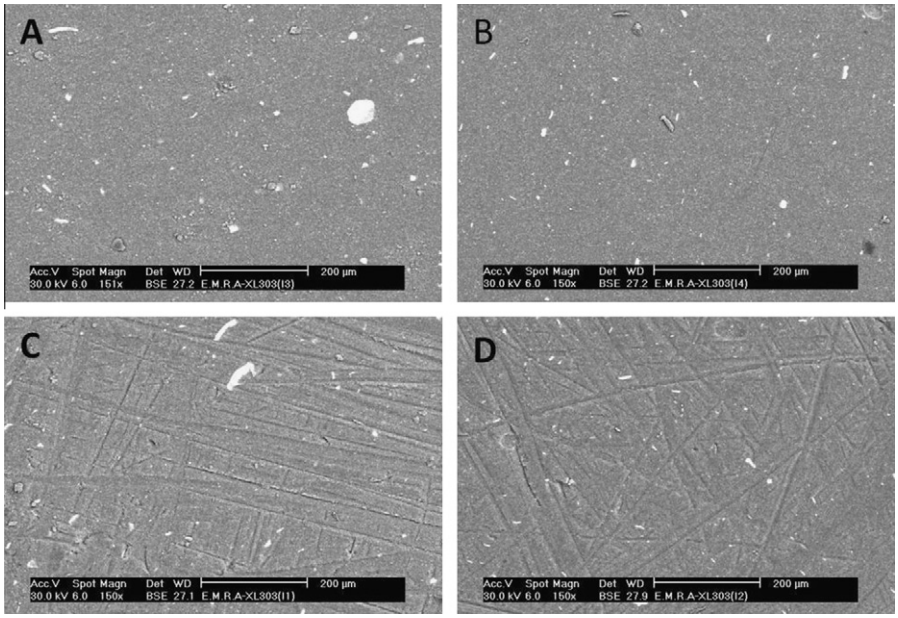

Fig. 2 SEM micrographs of Filtek P90 after different surface treatments 150×: (A) Smooth; (B) Smooth/acid etched; (C) Roughened; (D) Roughened/acid etched.

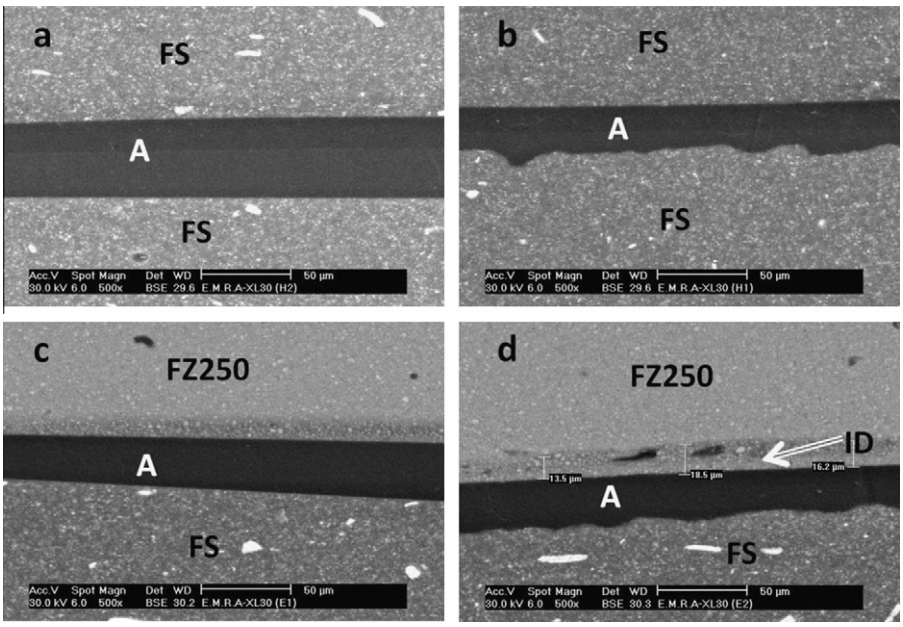

Fig. 3 SEM micrographs of Filtek P90 substrate-to-repair resin composite (FS) at 500×: (a) Smooth substrate repaired with P90 System Adhesive and Filtek P90 resin composite; (b) Roughened substrate repaired with P90 System Adhesive and Filtek P90 resin composite; (c) Smooth substrate repaired with SBMP and Filtek Z250 resin composite; (d) Roughened substrate repaired with SBMP and Filtek Z250 resin composite. A = adhesive layer; ID = interdiffusion zone.

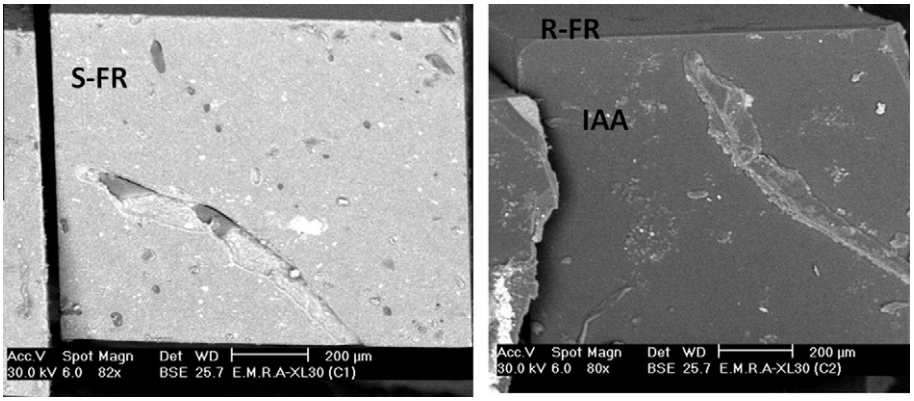

Fig. 4 SEM micrographs for representative two resulting surfaces of a stick after failure. S-FS = substrate of Filtek P90; R-FS = repair Filtek P90; IAA = intermediate adhesive agent. Left: Shows failure at substrate surface of Filtek P90; Right: Shows IAA attached to the repair Filtek P90.

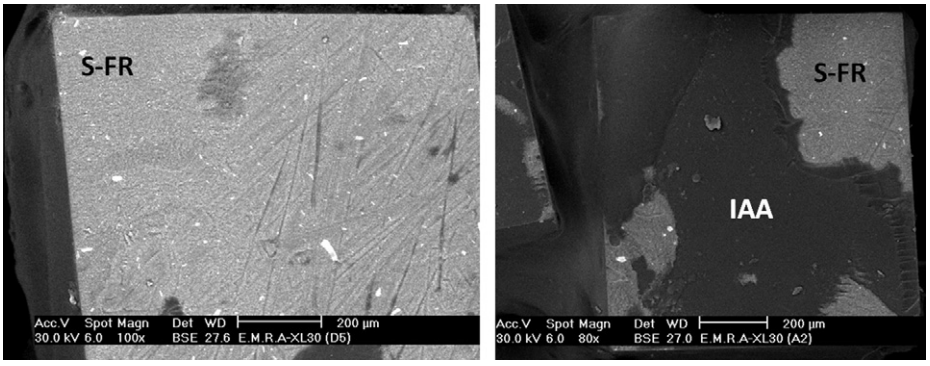

Fig. 5 SEM micrographs for representative stick after failure. S-FS = substrate of Filtek P90; R-FS = repair Filtek P90; IAA = intermediate bonding agent. Left: Shows adhesive failure at the roughened Filtek P90 substrate; Right: Shows mixed failure.

contribute to the repair mechanism [13,16,21]. The ability of monomers and solvent systems to penetrate into the composite surface depends on the chemical affinity of materials and the degree of hydration of the composites [7,33]. Most composites are hydrophobic in nature but contain some absorbed water that might improve surface penetration by hydrophilic bonding systems. The effectiveness of the studied adhesive systems may be improved by their low viscosity and hydrophilicity, which produces a small contact angle and good wetting properties [7,34,35].

An interesting point was that the difference between the intermediate adhesive systems in composition and in filler content (whether filled or not) did not influence the repairing bond strength outcome. However, no sufficient data is available regarding this issue. Previous researchers have claimed that the repair bond strength was much improved with filled adhesive resins than with unfilled adhesives [7]. This was based on the fact that the addition of fillers increases the cohesive strength. Regarding this point, further research is necessary.

Some investigators have reported that interfacial bond strength to fresh composite was not different from the cohesive strength of the resin composite itself [13]. On the other side, others reported that delayed repairing of resin composite revealed widely variable repair bond strengths, which are in the range of 25–82% of the cohesive strength of the substrate material [7,10,13,15,30]. In the present study, bond strength values of the repaired specimens were between 58% and 64% of the cohesive values of the Filtek P90 resin composite. This corresponds with others' findings although the test materials and methodologies are different [10,12,15]. Also, the obtained bond strength values could be considered within the acceptable limits according to Teixeira et al. [7]. However, such results should be interpreted with caution when applied to clinical situation because whether or not such values will survive in the oral environment is not yet validated. Therefore, long-term clinical performance of the repaired materials is the ultimate test. Further investigation regarding the clinical durability of the repair bond strength of silorane-based composite is still required.

Regarding the mode of failure, the present study showed the predominance of the adhesive failure mode which denotes that the repair interface is still the weakest part especially at the substrate side. The occurrence of failure mainly at the substrate side may indicate that there is higher bonding affinity between the IAS and the fresh repair composite more than that obtained between the IAS and the substrate composite. The detected inter-diffusion zone between SBMP and Filtek Z250 resin composite may support such speculation.

The previous findings emphasized that the evaluation of the quality of the bond should not be assessed on the basis of bond strength data alone. SEM observation of surface texture and observation of the mode of failure could provide important information that could potentially help in assessment of repair.

Conclusion

Repair of the silorane composite was successful irrespective of the surface roughness and chemistry of the repair material used, However, it did not reach the cohesive strength of the material.

Acknowledgement

Author would like to thank Mr. Mohamed El Shahat for the molds fabrication.

References

[1] Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. Dent Mater 2005;21(1):68–74.
[2] Ilie N, Jelen E, Clementino-Luedemann T, Hickel R. Low-shrinkage composite for dental application. Dent Mater J 2007;26(2):149–55.
[3] Palin WM, Fleming GJ, Burke FJ, Marquis PM, Randall RC. The influence of short and medium-term water immersion on the hydrolytic stability of novel low-shrink dental composites. Dent Mater 2005;21(9):852–63.
[4] Gordan VV, Mjor IA, Blum IR, Wilson N. Teaching students the repair of resin-based composite restorations: a survey of North American dental schools. J Am Dent Assoc 2003;134(3):317–23.
[5] Papacchini F, Dall'Oca S, Chieffi N, Goracci C, Sadek FT, Suh BI, et al. Composite-to-composite microtensile bond strength in the repair of a microfilled hybrid resin: effect of surface treatment and oxygen inhibition. J Adhes Dent 2007;9(1):25–31.
[6] Rodrigues Jr SA, Ferracane JL, Della Bona A. Influence of surface treatments on the bond strength of repaired resin composite restorative materials. Dent Mater 2009;25(4):442–51.
[7] Teixeira EC, Bayne SC, Thompson JY, Ritter AV, Swift EJ. Shear bond strength of self-etching bonding systems in combination with various composites used for repairing aged composites. J Adhes Dent 2005;7(2):159–64.
[8] Brosh T, Pilo R, Bichacho N, Blutstein R. Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. J Prosthet Dent 1997;77(2):122–6.
[9] Furuse AY, da Cunha LF, Benetti AR, Mondelli J. Bond strength of resin–resin interfaces contaminated with saliva and submitted to different surface treatments. J Appl Oral Sci 2007;15(6):501–5.
[10] Cavalcanti AN, De Lima AF, Peris AR, Mitsui FH, Marchi GM. Effect of surface treatments and bonding agents on the bond strength of repaired composites. J Esthet Restor Dent 2007;19(2):90–8.
[11] Bouschlicher MR, Reinhardt JW, Vargas MA. Surface treatment techniques for resin composite repair. Am J Dent 1997;10(6):279–83.
[12] Shahdad SA, Kennedy JG. Bond strength of repaired anterior composite resins: an *in vitro* study. J Dent 1998;26(8):685–94.
[13] Turner CW, Meiers JC. Repair of an aged, contaminated indirect composite resin with a direct, visible-light-cured composite resin. Oper Dent 1993;18(5):187–94.
[14] Molla K, Park HJ, Haller B. Bond strength of adhesive/composite combinations to dentin involving total- and self-etch adhesives. J Adhes Dent 2002;4(3):171–80.
[15] Bonstein T, Garlapo D, Donarummo Jr J, Bush PJ. Evaluation of varied repair protocols applied to aged composite resin. J Adhes Dent 2005;7(1):41–9.
[16] Gordan VV, Shen C, Riley 3rd J, Mjor IA. Two-year clinical evaluation of repair versus replacement of composite restorations. J Esthet Restor Dent 2006;18(3):144–53.
[17] Hannig C, Laubach S, Hahn P, Attin T. Shear bond strength of repaired adhesive filling materials using different repair procedures. J Adhes Dent 2006;8(1):35–40.

[18] Kallio TT, Lastumaki TM, Vallittu PK. Effect of resin application time on bond strength of polymer substrate repaired with particulate filler composite. J Mater Sci Mater Med 2003;14(11):999–1004.
[19] Shen C, Mondragon E, Gordan VV, Mjor IA. The effect of mechanical undercuts on the strength of composite repair. J Am Dent Assoc 2004;135(10):1406–12.
[20] Tezvergil A, Lassila LV, Vallittu PK. Composite–composite repair bond strength: effect of different adhesion primers. J Dent 2003;31(8):521–5.
[21] Sau CW, Oh GS, Koh H, Chee CS, Lim CC. Shear bond strength of repaired composite resins using a hybrid composite resin. Oper Dent 1999;24(3):156–61.
[22] Vankerckhoven H, Lambrechts P, van Beylen M, Davidson CL, Vanherle G. Unreacted methacrylate groups on the surfaces of composite resins. J Dent Res 1982;61(6):791–5.
[23] Swift Jr EJ, LeValley BD, Boyer DB. Evaluation of new methods for composite repair. Dent Mater 1992;8(6):362–5.
[24] Lewis G, Johnson W, Martin W, Canerdy A, Claburn C, Collier M. Shear bond strength of immediately repaired light-cured composite resin restorations. Oper Dent 1998;23(3):121–7.
[25] Tezvergil-Mutluay A, Lassila LV, Vallittu PK. Incremental layers bonding of silorane composite: the initial bonding properties. J Dent 2008;36(7):560–3.
[26] Shawkat ES, Shortall AC, Addison O, Palin WM. Oxygen inhibition and incremental layer bond strengths of resin composites. Dent Mater 2009;25(11):1338–46.
[27] Anusavice KJ. Philips' science of dental materials. 10th ed. Pennsylvania: W.B. Saunders Company; 1996, p. 298–99.
[28] Gordan VV. *In vitro* evaluation of margins of replaced resin-based composite restorations. J Esthet Dent 2000;12(4):209–15.
[29] Blum IR, Schriever A, Heidemann D, Mjor IA, Wilson NH. The repair of direct composite restorations: an international survey of the teaching of operative techniques and materials. Eur J Dent Educ 2003;7(1):41–8.
[30] Gregory WA, Pounder B, Bakus E. Bond strengths of chemically dissimilar repaired composite resins. J Prosthet Dent 1990;64(6):664–8.
[31] Luhrs AK, Gormann B, Jacker-Guhr S, Geurtsen W. Repairability of dental siloranes *in vitro*. Dent Mater 2011;27(2):144–9.
[32] Versluis A, Tantbirojn D, Douglas WH. Why do shear bond tests pull out dentin? J Dent Res 1997;76(6):1298–307.
[33] Lastumaki TM, Kallio TT, Vallittu PK. The bond strength of light-curing composite resin to finally polymerized and aged glass fiber-reinforced composite substrate. Biomaterials 2002;23(23):4533–9.
[34] Rosales-Leal JI, Osorio R, Holgado-Terriza JA, Cabrerizo-Vilchez MA, Toledano M. Dentin wetting by four adhesive systems. Dent Mater 2001;17(6):526–32.
[35] Toledano M, Osorio R, de Leonardi G, Rosales-Leal JI, Ceballos L, Cabrerizo-Vilchez MA. Influence of self-etching primer on the resin adhesion to enamel and dentin. Am J Dent 2001;14(4):205–10.